Potato Cultivar Differences Associated with Mealiness[†]

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Russet Burbank, Norchip, Pontiac, and LaSoda potato cultivars were examined for the parameters mealy and waxy. Russet Burbank was judged dry, hard and particulate, typifying mealiness. Using phase contrast microscopy and scanning electron microscopy, raw mealy cells were determined to be larger and more irregularly shaped than cells from waxy cultivars. Mealy cooked cells were engorged with gelatinized starch, cell walls were more polarized, and cell shapes were better retained after mashing, when compared to waxy cells. NMR-T2 bound water readings from Russet Burbank and Pontiac samples did not differ from each other. Starch granule sizes and shapes varied by cultivar.

Keywords: *Potato cultivar; texture; starch; microscopy*

INTRODUCTION

Recent recommendations for improvement of American diets have included increased consumption of fruits and vegetables (Slavin, 1987). Because potatoes can be successfully grown in a variety of soils and climates, they have been historically, and are today, an important crop in many countries (Hughes, 1991). Average annual per capita consumption of potatoes in the United States has continued to rise from 1970 to 1989, and the pounds consumed per capita far exceed the consumption of any other fruit or vegetable (Putnam, 1991). The *Better Homes and Gardens 1992 Consumer Panel Inquiry on Food* revealed that 94% of its survey group considered fresh potatoes to be staples usually kept on hand in the home, highest of all fruits and vegetables (Byal, 1992).

Color, flavor, and texture are important sensory attributes of potato cultivars for consumer acceptability. Consumers commonly base purchasing decisions of a potato cultivar mainly on textural qualities desired. Russet Burbank potatoes are preferred for baked and mashed potatoes because they have a dry and particulate mouth feel (defined as "mealy"). Better uniformity of color and lowered oil absorption are also obtained if these potatoes are used for frying and chipping (Russet Burbank and Norchip). However, when shape and cohesiveness are important, as in creamed potatoes or potato salad, red-skinned cultivars (Pontiac and LaSoda) are usually selected; these have been termed "waxy" potatoes because their texture is smooth with a moist gummy mouthfeel (Charley, 1982).

Studies have been conducted periodically to attempt to understand the reasons for textural differences among potato cultivars. Control of potato texture and perhaps other plant texture in food processing, in home preparation, and in new cultivar development could benefit from an understanding of the differences that cause variable sensory responses.

Previous studies conducted with the same cultivars (Russet Burbank, Pontiac, LaSoda, and Norchip) obtained from the USDA Potato Research Laboratory growers' seed stocks indicated that specific gravity, often used by industry as an indication of mealiness, was not correlated with sensory panel scores of texture of four cultivars. Differences in swelling powers, gelatinization temperatures, and amylograph viscosities of extracted starches did not explain sensory properties (McComber et al., 1988). Therefore, additional analyses of the same cultivars and their extracted starches were employed. Light microscopy, scanning electron microscopy, and image analysis were used to determine size, shape, and appearance of the raw, cooked, and mashed cells and cell walls, middle lamellae, starches within the raw and cooked cells, and raw starches extracted from the cells. Cation and nuclear magnetic resonance measurements were conducted to identify any differences in the presence of certain elements and potential water binding capacity. Various cations have been shown to correlate with sensory evaluations of mealiness (Hughes et al., 1975a,b; Mica and Brod, 1985; Warren and Woodman, 1974). Sensory panels were used to confirm textural qualities of the potatoes studied on the days they were cooked for microscopic examinations as well as on the days cation and nuclear magnetic resonance measurements were made.

MATERIALS AND METHODS

Russet Burbank (mealy), Norchip (sometimes mealy), and Pontiac and LaSoda (waxy) potato cultivars were obtained from the USDA Potato Research Laboratory in East Grand Forks, MN, from seed stock. These cultivars were harvested and tested during several growing seasons. All were sprayed with isopropyl *m*-chlorocarbanilate (Sprout Nip) before storage to prevent sprouting. Potatoes were stored from 1 to 4 months at 7 °C in a cold room. Before observation or measurement, they were conditioned at room temperature (20 °C) for 3–5 days. Only the central pith tissue from the stem half of each potato was used. Previous work determined that stem ends of each cultivar differed from the other cultivars more than bud ends (McComber et al., 1987, 1988). Sampling from potatoes, specific gravity determinations, and cooking procedures have been described in an earlier study (McComber et al., 1987). By cutting raw potatoes with a cylinder, all samples were the same size and shape. Samples were cooked by steaming for 25 min. Samples were cut with a smaller cylinder after steaming to avoid using any sample affected by the

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surface moisture from the steam. From these samples, smaller portions were removed for the sensory tests, microscopy, nuclear magnetic resonance, and cation analyses. When cooked potatoes were mashed, similar small samples were pressed through a potato ricer. Because of limitations of time and of sample material, certain tests were conducted with only two of the four cultivars mentioned. Russet Burbank and Pontiac were selected for these tests because they were considered to represent mealy and waxy cultivars, respectively.

Sensory Analyses. A seven-member sensory panel was recruited from student and faculty volunteers. Prior to evaluation, panelists were trained regarding anchor points, attribute characteristics, and use of the score card with Russet Burbank and red-skinned potatoes from local supplies. Mealy potatoes have been described as more dry and more hard and with a more particulate mouthfeel than waxy potatoes (McComber et al., 1988). Panelists agreed to the ratings from 1, indicating not dry, not hard, and not particulate, to 9, indicating extremely dry, hard, and particulate. Judgments were derived from exactly the same core samples of potatoes used on the days nuclear magnetic resonance and cation measurements were taken and on the days potatoes were sampled for microscopy. Two to four samples were presented to the panel each time, depending on whether all four cultivars or only the Russet Burbank and Pontiac cultivars were being compared. A total of 18 Russet Burbank and Pontiac potatoes each were analyzed along with 9 Norchip and 9 LaSoda potatoes.

Nuclear Magnetic Resonance (NMR). A total of five potatoes each from Russet Burbank and Pontiac cultivars were tested at three different times to determine any differences in bound water that might explain the sensory scores for moisture. Each whole potato was analyzed for specific gravity before cooking. Specific gravity was determined by dividing the air weight of each potato by the difference of its water weight subtracted from its air weight. Sample sensory scores and NMR analyses were performed within a 6-h time period. All samples for NMR were kept in closed containers to prevent drying. Samples were identified so that the specific gravity, sensory scores, and NMR data could be compared for each potato. Two-pulse NMR was measured in milliseconds with a Bruker MSL 300 to obtain readings on the water component. The NMR-T2 data were calculated by the computer system associated with the NMR. Standardization techniques were employed on each day. Two or three readings were measured from each potato pith sample as previously described.

Cation Analyses. Two samples of Russet Burbank and Pontiac cultivars were selected for cation analyses. One-gram samples were added along with 5 mL of distilled deionized water and 5 mL (metals grade) of nitric acid to 250-mL flasks with reflux adapters. Each mixture was heated slowly to begin dissolution of the sample; an additional 5 mL of nitric acid was added and heated at reflux until each sample was in solution. Samples were analyzed by flame atomic absorption for calcium and magnesium or by flame emission for sodium and potassium. One sample was presented with known amounts of each element to provide internal standards.

Image Analysis, Potato Starches. Extracted, raw starches from the four cultivars were analyzed for size and shape to determine if any differences could be compared with swelling of the same starches in cooked cells. Starch grains were analyzed with a Zeiss SEM-Ips image analysis system (Zeiss-Kontron; IBAS version 1.31). For each starch sample, at least 500 particles were analyzed for total area and fit to a circle. The starch grains were placed on a Zeiss Axiophot microscope, observed with bright-field optics, and viewed with a Sony 3 CCD color video camera using the 10× objective. Particles that touched each other were cut apart interactively. Scanning electron microscopy of the isolated starch grains was conducted using the same four cultivars.

Scanning Electron Microscopy. Raw and cooked potato segments from each of the four cultivars were frozen cryogenically with liquid nitrogen, freeze-fractured, freeze-etched for 12–20 min, and gold-coated in an EMscope 2400 cryopreservation system. Frozen specimens were transferred to a cold stage (−150 °C) in a JEOL JSM-35C scanning electron microscope. Microstructures were photographed at 15 kV and 60 μA beam current using Polaroid Type 665 film.

Table 1. Means of Sensory Scores,[a] Specific Gravities, and NMR-T2 Readings for Potato Cultivars

variable	Russet Burbank	Pontiac	P^b
dryness	5.40	3.20	0.03
hardness	6.40	4.30	<0.01
particulate	5.80	3.40	<0.01
specific gravity	1.09	1.08	<0.01
NMR-T2, ms	14.16	15.14	<0.46

[a] Sensory scores with higher numbers are more dry, more hard, and more particulate, typifying mealy potatoes. [b] Probability the cultivar difference is due to chance alone.

Light Microscopy. Two low and two high specific gravity (to determine the effect of specific gravity) potatoes of Russet Burbank and Pontiac cultivars, five raw and five steamed potatoes of all four cultivars, and two steamed and two mashed potatoes of Russet Burbank and Pontiac cultivars were processed for microscopy. A sensory panel was utilized to evaluate the qualities of each cultivar just before potatoes were chemically preserved. All samples were fixed in 3% paraformaldehyde–2% glutaraldehyde in a 0.05 M sodium cacodylate buffer, pH 7.2, at room temperature. Dehydration was in an ethanol series, 2-h intervals, to pure LR White resin. A 1-week resin infiltration time was utilized to ensure resin homogeneity before polymerization was initiated. Polymerization of the resin was at 60 °C for 48 h. Sections of samples cut 1–2 μm thick were mounted unstained or stained with aqueous basic fuchsin (0.26%) to show primary cell walls, middle lamellae, and cellular contents or with aqueous ruthenium red (1:5000) to identify just the middle lamellae. Mounted stained and unstained sections were covered with Permount and coverslips. Observations were made on a Leitz Orthoplan microscope using polarized light, bright-field, and phase contrast imaging. Images were recorded with Kodak Techpan film.

Statistics. Statistical evaluations of results found in these studies came from the outcomes of analyses of variance based on the assumptions of approximate homogeneous variance and normally distributed residuals.

RESULTS AND DISCUSSION

Sensory Scores, Specific Gravity, and NMR. Mealy texture in potatoes has been evaluated by sensory panelists as being more hard, more dry, and more particulate than waxy potatoes (McComber et al., 1988). Waxy potatoes have been described as moist, mushy, and smooth. In this study, the Russet Burbank cultivar is significantly more dry, more hard, and more particulate and has a higher specific gravity than the Pontiac cultivar (Table 1). The mealy character of the Russet Burbank cultivar confirms previous results (Barrios et al., 1963; McComber et al., 1988), while the waxy texture of the Pontiac potato has been found to be typical of the cultivar (McComber et al., 1988; Unrau and Nylund, 1957). However, the precise role of specific gravity and of the starch content remains unclear (Barrios et al., 1961; Iritani and Weller, 1974; Iritani et al., 1977; McComber et al., 1988; Mica and Brod, 1985; Unrau and Nylund, 1957).

The difference in the NMR means for Russet Burbank and Pontiac (Table 1) is not statistically significant. However, sensory panel scores did demonstrate a sensitivity to moisture binding (compare sensory with NMR results in Table 1). Evidence that a single T2 reading may not identify the binding of water has been reported (Lee et al., 1992). Additional studies dealing with intracellular and intercellular distribution of water may provide more information about moisture status.

Table 2. Means of Cation Analyses from Cooked Potato Cultivars

	μg/g			
	Na	K	Ca	Mg
Russet Burbank	18	2500	62	240
Pontiac	26	3290	42	220

Table 3. Mean Values from Image Analyses of Pooled Samples of Starches from Four Cultivars

	Russet Burbank	Pontiac	Norchip	LaSoda	lsd[a]
area, no. of pixels	831	496	696	435	116
fit to circle[b]	0.78	0.80	0.80	0.79	0.03

[a] lsd, least significant difference ($P = 0.05$, df = 3). [b] A value of 1.0 indicates perfect circularity.

Ion Concentrations. Data indicate that mealy Russet Burbank potatoes, as compared to waxy Pontiac potatoes, have a higher concentration of calcium and magnesium and a lower concentration of sodium and potassium (Table 2). Calcium and magnesium have been shown to contribute mealiness (Mica and Brod, 1985) and strength to the potatoes they tested, while monovalent ions reduced strength (Hughes et al., 1975a,b). Russet Burbank is harder than Pontiac (Table 1). Warren and Woodman (1974) pointed out that calcium and magnesium in potatoes could increase viscosity and intercellular adhesion by providing salt linkages in the polyuronide material.

Characteristics of Isolated Starch Granules. Russet Burbank and Norchip starch granule areas differ from each other and from the other two cultivars (Table 3). The largest granules are found in Russet Burbank with LaSoda and Pontiac providing the smallest average size of granules. For circularity or granule roundness, there are no significant cultivar differences. Representative scanning electron micrographs showing isolated granules of the four cultivars are presented in Figure 1A–D. Briant et al. (1945) correlated lower mealiness with a high percentage of small starch granules, while Barrios et al. (1961, 1963) found larger granules in mealy Russet Burbank than in LaSoda. However, starch granule size has not been found to be related to mealiness by other researchers (Unrau and Nylund, 1957).

Scanning Electron Microscopy (SEM). Comparisons of the raw, quick-frozen samples of the four cultivars show that Russet Burbank cells (Figure 1E) are larger than Pontiac (Figure 1F), LaSoda (Figure 1G), and Norchip (Figure 1H) cells. After cooking, adjacent cell wall–middle lamella complexes of Russet Burbank (Figure 2A) appear swollen and appressed to each other in contrast to the thin middle lamellae separated from their adjacent walls in the other three cultivars (Figure 2B–D). None of the cells of these four cultivars are completely filled with starch grains. This agrees with sectioned images of chemically fixed samples of the four cultivars observed with light microscopy (see Figure 3A–D).

Light Microscopy (LM). Similar to the SEM images, raw Russet Burbank generally appears to have the largest cells of the four cultivars (Figure 3A–D does not show these differences as clearly as Figure 1E–H). Russet Burbank cells display polyhedral shapes and slightly thinner middle lamellae when stained with ruthenium red (not shown). Otherwise, the combined thickness of the two adjacent cell walls and included middle lamella does not appear to be appreciably different among the four cultivars. As already shown with SEM, none of the cells from the four cultivars is completely filled with starch when observed in 1 μm thick resin sections (Figure 3A–D). The starch grains vary in size, and the remaining cellular regions contain cell organelles and unstained spaces.

Cooked Russet Burbank cells are typically larger and more varied in shape, and the adjacent cell walls and middle lamellae are thicker (Figure 3E). The middle lamellae are also slightly more polarized (not shown) than the other three cultivars (Figure 3F–H), suggesting they are capable of maintaining cell to cell binding. Reeve (1977) described Russet Burbank cells as being polyhedral in shape. However, we did not observe any of the cells to be "rounded off" as was the sloughed Russet Burbank tissue examined by Reeve (1977) or the mealy sweetpotato described by Sterling and Aldridge (1977). Even the intercellular spaces are not appreciably different. These contrasting observations may be the result of our samples being taken from the inner pith region of the cooked potatoes. Our results support Bretzloff (1970), who did not observe any change in size or shape of Russet Burbank cells after cooking.

In addition to the difference in the cooked cell wall–middle lamella complex between Russet Burbank and the other three cultivars, the amount of gelatinized starch filling the cells is striking. Cooked Russet Burbank cells are completely engorged with gelatinized starch (Figure 3E), in contrast to the other three cultivars (Figure 3F–H), which appear to be only 30–50% filled. In all four cooked cultivars the cells are intact and not collapsed. These observations support the greater hardness of Russet Burbank, as noted by sensory panels and by the resistance to shear (McComber et al., 1987, 1988).

Mica and Brod (1985) reported that differences in behavior of various starches during heating may be more significant to the texture of cooked potatoes than differences in the amounts of starch among cultivars. While no differences in gelatinization temperatures and amylograph and swelling behavior of extracted starches could be ascribed to textural characteristics (McComber et al., 1988), starches gelatinized in intact cells may behave very differently, with the Russet Burbank grains swelling to occupy the entire cellular space. Cooked, mealy sweetpotato cells have been shown to be filled with gelatinized starch, while soggy yam cells had less visible gelatinized starch (Sterling and Aldridge, 1977).

Cell wall separation is not observed in any of our cooked cultivars whether or not they are engorged with gelatinized starch. This is in contrast to the findings of Loh et al. (1982), who observed that some cell separation of Pontiac occurred after 1 min of steaming. Warren and Woodman (1974) demonstrated that the lumens of adjoining potato cells increased when potatoes were cooked. They theorized that the greater hydration and the increased water uptake would result in lowered viscosity and less cell adhesion, typical of potatoes that tend to slough. Loh et al. (1982) found no increase in cell wall thickness after cooking Pontiac potatoes. Even though the cell wall–middle lamella complexes are intact in all four cultivars in our study, there is a perceptible decrease in the middle lamella staining of all four cultivars. However, the walls of Pontiac, LaSoda, and Norchip show less wall polarization compared to Russet Burbank.

Cooked high and low specific gravity Russet Burbank (Figure 3I,J) and Pontiac (Figure 3K,L) show differences

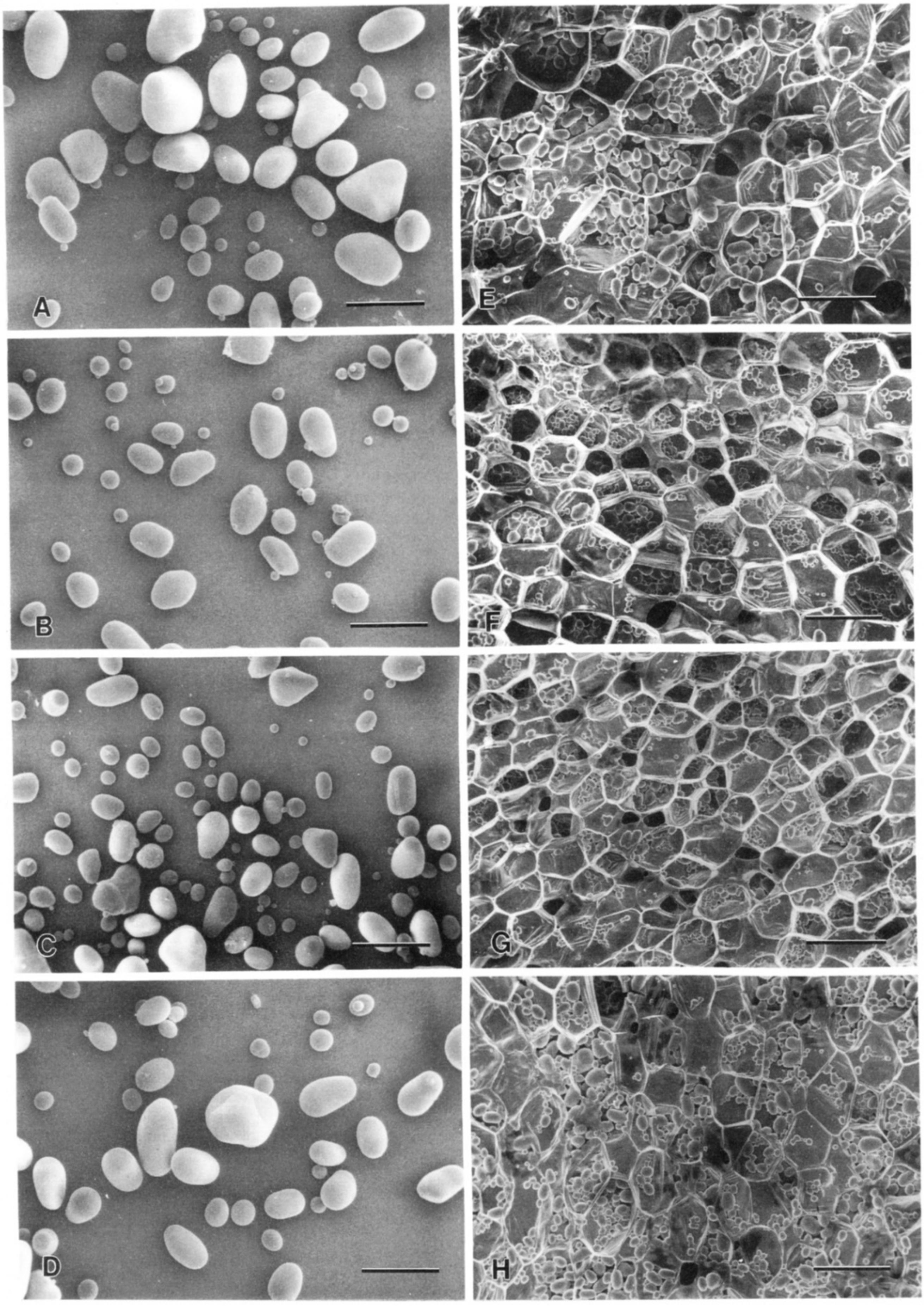

Figure 1. Scanning electron micrographs of isolated starch granules (A–D; bars equal 75 μm) and freeze fracture faces (E–H; bars equal 300 μm) of four raw potato cultivars. Note variation in sizes of starch grains. (A) Russet Burbank; (B) Pontiac; (C) LaSoda; (D) Norchip; note variation in sizes of cells. (E) Russet Burbank; (F) Pontiac; (G) LaSoda; (H) Norchip.

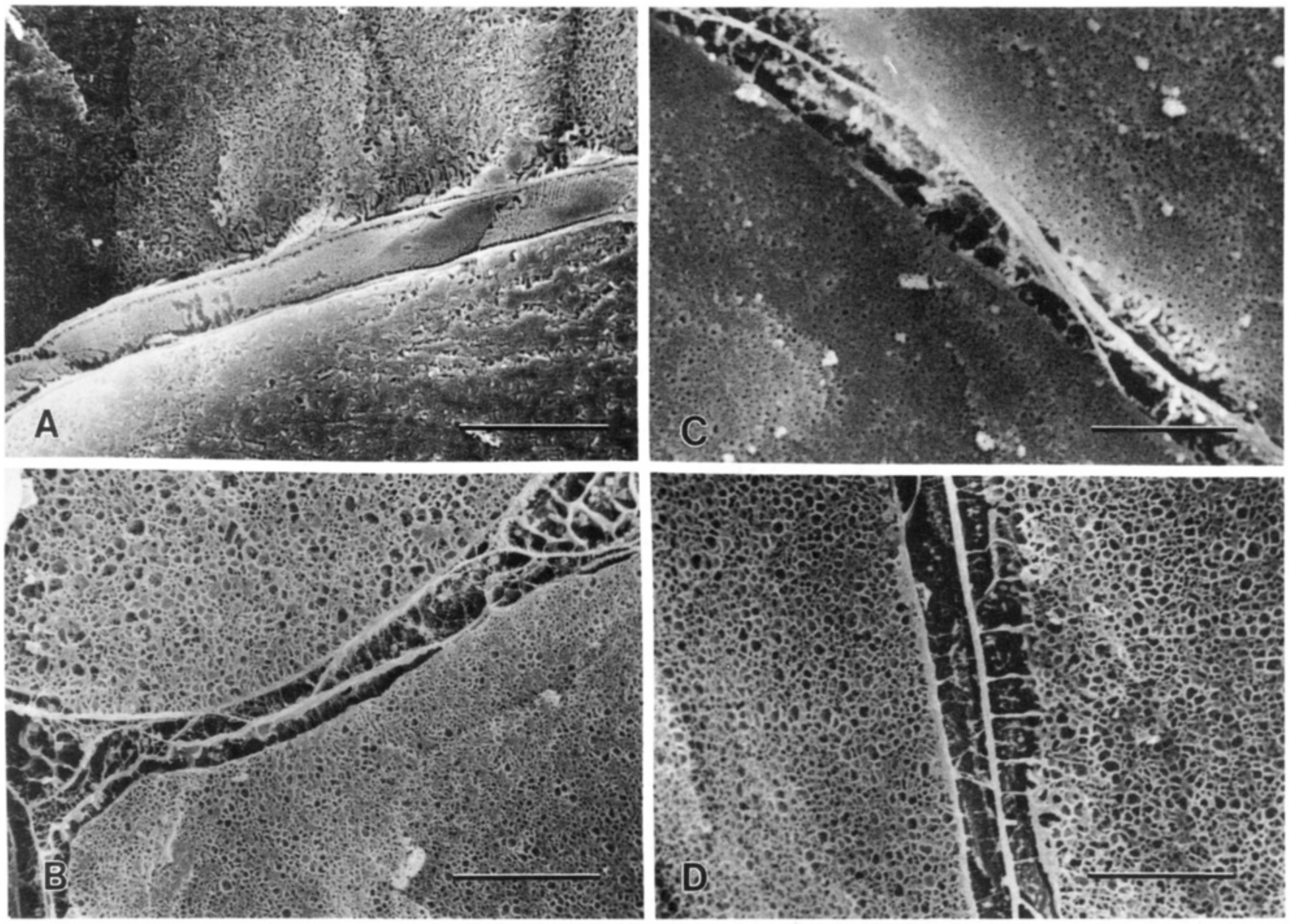

Figure 2. Scanning electron micrographs of portions of freeze-fractured cooked (steamed) cells and common wall region of four potato cultivars. All four cultivars show cytoplasm and gelatinized starch as fine spongy matrix. Appearances of common wall region containing adjacent cell walls and middle lamella are clearly different between Russet Burbank and the other three cultivars. All bars equal 20 μm. (A) Russet Burbank; (B) Pontiac; (C) LaSoda; (D) Norchip.

in compaction after mashing. Russet Burbank cells are generally less compact than Pontiac cells. After ricing, Pontiac cells are more flattened and, as a result, appear to be filled with starch (Figure 3L). Some cells are separated from each other and are broken (not shown). These results support those of Nonaka (1980), who did not observe any changes in cellular shapes in mashed Russet Burbank. He discounted the theory that cells may swell, round off, and then break apart into a mealy mass. However, cooked and cooked and mashed mealy Russet Burbank in our study, in contrast to Pontiac, depicts fully engorged cells surrounded by thickened cell wall–middle lamella complexes that resist deformation when mashed. The cells may be more susceptible to breaking into particulate masses versus collapsing. Our results support the suggestions of Reeve (1977) and Iritani et al. (1977) that textural qualities must be described by both the starch in the cells and the cell wall components.

Overview. The dry character of cooked Russet Burbank may be imparted by the increased volume of the gelatinized starch, which completely engorges its cells. While the remainder of the cells of the waxy cultivars appear to be less filled when viewed with light microscopy because of the chemical dehydration in processing, SEM of frozen fixed samples reveals the presence of a cytoplasmic matrix filling each cell. Cells are no doubt filled with water and other dissolved substances, or the cooked cells would have collapsed. We speculate that when the pressure of the teeth, mouth, and tongue are exerted on cooked waxy potato segments, they release the loosely held water not associated with gelatinized starch. This imparts the moist character described by the sensory panel. Previous tests with mealy and waxy potatoes confined in a shear box (McComber et al., 1987) resulted in small amounts of free water after direct shearing of waxy potatoes; there was no detectable moisture after shearing of mealy Russet Burbank. These results suggest that the gelatinized starch filling each mealy cell better retains the water, giving it the "dry" characteristic.

When starches are extracted from each cultivar, it is not possible to observe differences that can be ascribed to dryness (McComber et al., 1988). Therefore, it seems that differences in extracted starches do not necessarily reflect the behavior of starches within cells that could be affected by other unidentified cellular contents. Raw starch granules in uncooked potato cells do not show a great deal of difference among the four cultivars studied. However, complete engorgement of Russet Burbank cells with gelatinized starch after cooking is very different from that of the three less mealy cultivars.

Sensory differences in cultivars include a particulate mouthfeel by cooked mealy Russet Burbank. Microscopically, both the cell walls and the middle lamellae of this cultivar are thicker than those of the less mealy cultivars. Calcium and magnesium ion concentrations are higher in Russet Burbank, in contrast to Pontiac, and may provide strength to the pectic substances. If Russet Burbank cells are supported by filled masses of

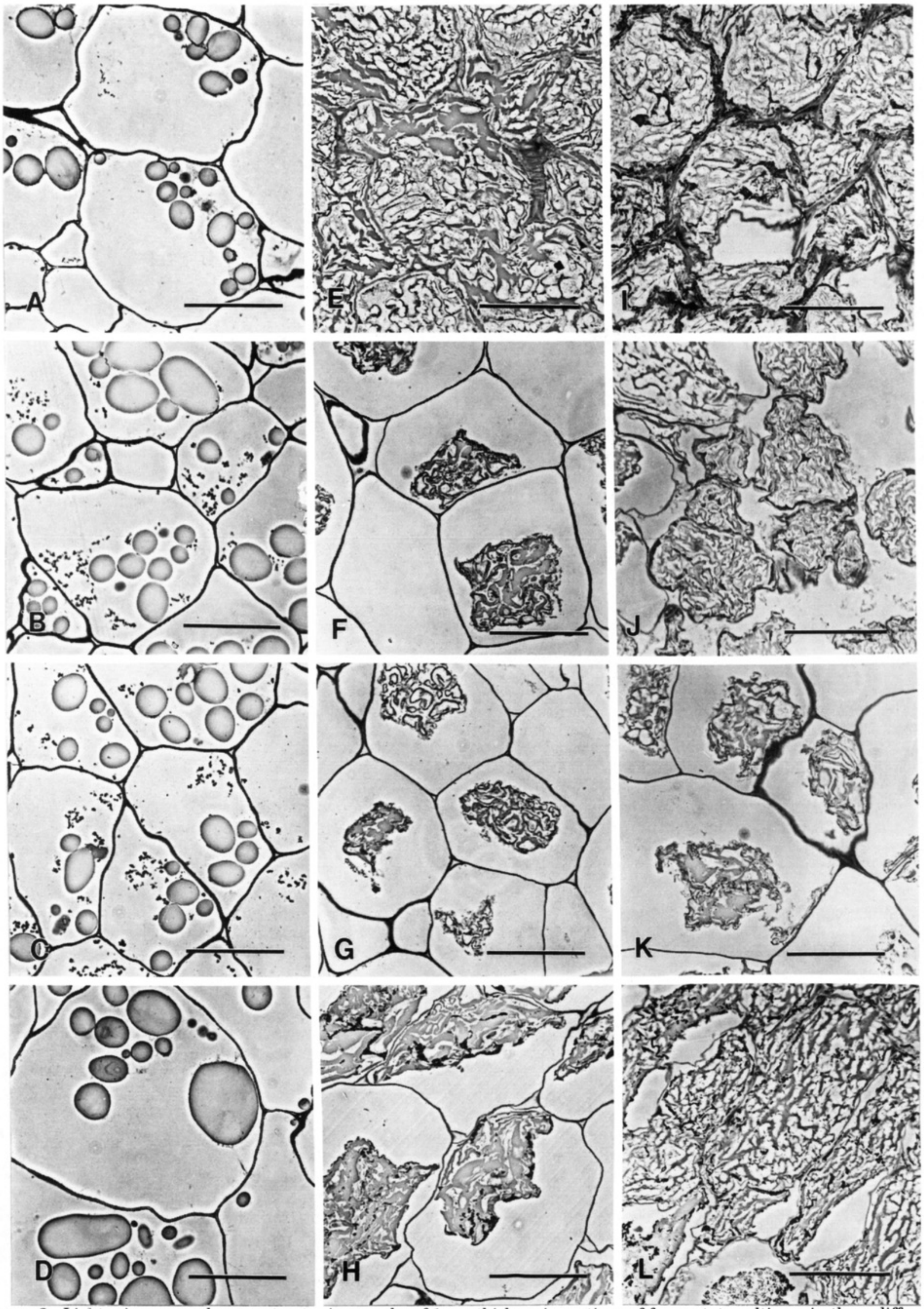

Figure 3. Light microscope phase contrast micrographs of 1 μm thick resin sections of four potato cultivars in three different conditions: raw; cooked (steamed); and cooked (steamed) and mashed. Note variations in size and shape of cells, starch granules, and gelatinized starch masses. All bars equal 75 μm. (A–D) Raw, (A) Russet Burbank [specific gravity (sp gr) 1.09], (B) Pontiac (sp gr 1.08), (C) LaSoda (sp gr 1.08), (D) Norchip (sp gr 1.08); (E–H) cooked (steamed), (E) Russet Burbank (sp gr 1.09), (F) Pontiac (sp gr 1.08), (G) LaSoda (sp gr 1.08), (H) Norchip (sp gr 1.09); (I–L) cooked (steamed) and mashed, (I) Russet Burbank (high sp gr 1.09), (J) Russet Burbank (low sp gr 1.06), (K) Pontiac (high sp gr 1.06), (L) Pontiac (low sp gr 1.05).

gelatinized starch and the cell walls and middle lamellae are strengthened by more calcium and magnesium bonds, the cells may resist separation when shear is applied to them. Therefore, groups of fractured cells from Russet Burbank may account for the particulate mouthfeel, as well as hardness, described by sensory panels. Our results support the suggestions by Reeve (1977) and Iritani et al. (1977) that textural qualities must be described by both the starch in the cells and the cell wall components. Furthermore, our results do not support the contention that specific gravity is directly related to mealiness.

Future studies should concentrate on cation content, and on the degree of gelatinization of starch in intact cells and the factors that control it. Use of a sensory panel should be included in these studies since it serves as a documented sensitive system for combining several characters that define texture, namely mealiness.

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